geology of the country south of Lake Erie, suggested by the work of the New Geological Survey of Pennsylvania; the most important of these changes, namely, the adoption of an east and west strike for a northeast and southwest strike, being necessitated by the probability that most of the exposures of conglomerate throughout Warren, Venango, and Crawford Counties in Pennsylvania, and Cattaraugus and Chautauque Counties in New York, belong to a horizon 200 feet below that of the Great Conglomerate, No. XII, the base of the Productive Coal Measures.

Dr. Cresson referred to the discussion of thermo-electric currents at the last meeting to state his own opinion that it is not needful to have two metals, or an unhomogeneous mass of one metal for the exhibition of such currents. He had found water alone to be a sufficient medium for the production and exhibition of the phenomena under discussion.

The minutes of the last meeting of the Board of Officers and Members in Council were read.

Pending nomination, No. 780, and new nominations, No. 781 and 782 were read.

And the meeting was adjourned.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE UNIVERSITY OF PENNSYLVANIA.

No. I.

A NEW VERTICAL-LANTERN GALVANOMETER.

By George F. Barker, M.D., Professor of Physics.

(*Read before the American Philosophical Society, May 7th*, 1875.)

Desiring to show to a large audience some delicate experiments in magneto-electric induction, in a recent lecture upon the Gramme machine, a new form of demonstration galvanometer was devised for the purpose, which has answered the object so well that it seems desirable to make some permanent record of its construction.

Various plans have already been proposed for making visible to an audience the oscillations of a galvanometer needle; but they all seem to have certain inherent objections which have prevented them from coming into general use. Perhaps the most common of these devices is that first used by Gauss in 1827, and adopted subsequently by Poggendorff and by Weber, which consists in attaching a mirror to the needle. By this means, a beam of light may be reflected to the zero point of a distant scale, and any deflection of the needle made clearly evident. The advantages of this method are :—1st, the motion of the needle may be indefinitely magnified by increasing the distance of the scale, and this without impairing the delicacy of the instrument; and 2d, the angular deflection of the needle is doubled by the reflection. These unquestioned advantages have led to the adoption of this method of reading in the most excellent galvanometers of Sir William Thomson. While therefore, for purposes of research, this method seems to leave very little to be desired, yet for purposes of lecture demonstration it has never come into very great favor; perhaps because the adjustments are somewhat tedious to make, and because, when made, the motion to the right or left of a spot of light upon a screen fails of its full significance to an average audience.

Another plan is that used by Mr. Tyndall in the lectures which he gave in this country. In principle, it is identical with that employed in the megascope; *i. e.*, a graduated circle over which the needle moves is strongly illuminated with the electric light, and then by means of a lens a magnified image of both circle and needle is formed on the screen. The insufficient illumination given in this way, and the somewhat awkward arrangement of the apparatus required, have prevented its general adoption.

A much more satisfactory arrangement was described by Professor Mayer in 1872,* in which he appears to have made use, for the first time, of the excellent so-called vertical lantern in galvanometry. Upon the horizontal plane face of the condensing lens of this vertical lantern, Mayer places a delicately balanced magnetic needle, and on each side of the lens, separated by a distance equal to its diameter, is a flat spiral of square copper wire, the axis of these spirals passing through the point of suspension of the needle. A graduated circle is drawn or photographed on the glass beneath the needle, and the image of this, together with that of the needle itself, is projected on the screen, enlarged to any desirable extent. The defect of this apparatus, so excellent in many respects, seems to have been its want of delicacy; for in the same paper the use of a flat narrow coil, wound lengthwise about the needle, is recommended as better for thermal currents. Moreover, a year later, in 1873,† Mayer described another galvanometer improvement, entirely different in its character. In this latter instrument, the ordinary astatic galvanometer of Melloni was made use of, an inverted scale being drawn on the inside of the shade, in front of which traversed an index in the form of a small acute rhomb, attached to a balanced arm transverse to the axis of suspension of the needle, and moving with it. The scale and index were placed in front of the condensing lenses of an ordinary lantern, and their

*American Journal of Science, III, iii, 414, June 1872.

†American Journal of Science, III, v, 270, April, 1873.

images were projected on the screen in the usual way by use of the objective. This instrument is essentially the same in principle as the mirror galvanometer ; but it cannot be as sensitive as the latter, while it is open to the same objection which we have brought against this—the objection of unintelligibility. In the hands of so skillful an experimenter as Mayer, it seems, however, to have worked admirably.

It was a tacit conviction that none of the forms of apparatus now described would satisfactorily answer all the requirements of the lecture above referred to, that led to the devising of the galvanometer now to be described, which was constructed in February of the present year. Like the first galvanometer of Mayer, the vertical lantern, as improved by Morton,* forms the basis of the apparatus. This vertical lantern, as constructed by George Wale & Co., at the Stevens Institute of Technology, as an attachment to the ordinary lantern, is shown in the annexed cut, figure 1. Parallel rays of light, from the lantern in front of which it is placed, are received upon the mirror, which is inclined 45° to the horizon, and are thrown directly upward, upon the horizontal plano-convex lens just above. These rays, converged by the lens, enter the object glass, and are thrown on the screen by the smaller inclined mirror placed above it. The upper face of the lens forms thus a horizontal table, upon which water-tanks, etc., may be placed, and many beautiful experiments shown. To adapt this vertical lantern to the purposes of a galvanometer, a graduated circle, photographed on glass, is placed upon the horizontal condensing lens. Above this, a magnetic needle, of the shape of a very acute rhomb, is suspended by a filament of silk, which passes up through a loop formed in a wire, stretched close beneath the object glass, and thence down to the side pillar which supports this objective, where it is fastened by a bit of wax, to facilitate adjustment. The needle itself is fixed to an aluminum wire, which passes down through openings drilled in the scale glass, the horizontal lens, and the inclined mirror, and which carries a second needle near its lower end.† Surrounding this lower

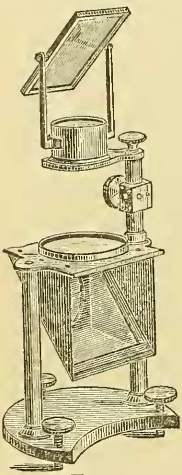

Fig. 1.

*Jour. Frank. Inst., III, lxi, 300, May, 1871; Am. J. Sci., III, ii, 71, 153, July, Aug., 1871; Quar. J. Sci., Oct., 1871. In Duboscq's vertical attachment, which was advertised in his catalogue in 1870, the arrangement is similar, except that the beam received upon the mirror is a diverging one, and consequently the horizontal lens is of shorter focus. A total reflection prism, placed above the object glass, throws the light to the screen. The instrument gives a uniformly illuminated but not very bright field.

† After the new galvanometer was completed and had been in use for several weeks, I observed, in re-reading Mayer's first paper, a note stating that the idea had occurred to him of using an astatic combination consisting of two needles, one above the lens and the other below the inclined mirror—the two being connected by a stiff wire passing through holes in the condenser and the mirror. The plan of placing the coil round the lower needle does not seem to have suggested itself to him. Indeed, it does not appear that the arrangement he mentions was ever carried into practical effect.

needle is a circular coil of wire, having a cylindrical hollow core of an inch in diameter, in which the needle swings, and a smaller opening transverse to this, through which the suspension wire passes. In the apparatus already constructed (in which the upper needle is five centimeters long,) the coil is composed of 100 feet of No. 14 copper wire, and has a resistance of 0 235 ohm. The accompanying cross section (Fig. 2,) of the vertical-lantern galvanometer as at present arranged, drawn on a scale of $\frac{1}{12}$, will serve to make the above description more clear. A is the needle, suspended directly above the scale-glass D, by a silk filament, passing through the loop B, close under the objective C. This needle is attached to the aluminum wire *a b*, which passes directly through the scale-glass D, the condensing lens E, and the inclined mirror F at H, and carries, near its lower end, the second needle I. This needle is shorter, (its length is 2.2 centimeters,) and heavier than the upper one, and moves in the core of the circular coil J, whose ends connect with the screw-cups at K. This coil rests on the base of the lantern, enclosed in a suitable frame. It is obvious that when the instrument is so placed that the coil is in the plane of the magnetic meridian, any current passing through this coil will act on the lower needle, and, since both needles are attached to the same wire, both will be simultaneously and equally deflected. Upon the screen is seen only the graduated circle and the upper needle ; all the other parts of the apparatus are either out of the field or out of focus. Moreover, the hole in the lens is covered by the middle portion of the needle, and hence is not visible. The size of the image is, of course, determined by the distance of the galvanometer from the screen ; in class experiments, a circle 8 feet in diameter is sufficient ; though in the lecture above referred to, the circle was 16 feet across, and the needle was fourteen feet long, the field being brilliant.

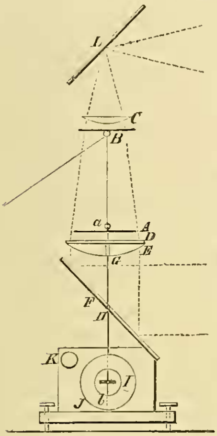

Fig. 2.

The method of construction which has now been described, is evidently capable of producing a galvanometer for demonstration, whose delicacy may be determined at will, depending only on the kind of work to be done with it. In the first place, the needles may be made more or less perfectly astatic, and so freed more or less completely from the action of the earth's magnetism, and consequently more or less sensitive. Moreover, an astatic system seems to be preferable to one in which damping magnets are used, since it is freer from influence by local causes ; though, if desirable for a coarser class of experiments, the considerable distance which separates the needles in this instrument, allows the use of a damping magnet with either of them. In the galvanometer now in use, the upper needle is the stronger, and gives sufficient directive tendency to the system to bring the deflected needle back to zero quite promptly. In the experiments referred to below, the system made 25 oscillations per minute.

Secondly, the space beneath the mirror is sufficiently large to permit the use of a coil of any needed size. Since, therefore, the lower needle is entirely enclosed within the coil, the field of force within which it moves, may be made sensibly equal at all angles of deflection, as in the galvanometers of Sir Wm. Thomson. Hence the indications of the instrument may be made quantitative, at least within certain limits. The circular coil, too, has decided advantages over the flat coil, since the mass of wire being nearer to the needle, produces a more intense field. Were it desirable, a double coil, containing an astatic combination could be placed below the mirror, the upper needle, in that case, serving only as an index. The instrument above described has a coil three inches in diameter and one inch thick; the diameter of the core being one inch. Since its resistance is only about a quarter of an ohm it is intended for use with circuits of small resistance, such as thermo-currents and the like.

The results of a few experiments made with this new vertical-lantern galvanometer will illustrate the working of the instrument, and will demonstrate its delicacy. The apparatus used was not constructed especially for the purpose, but was a part of the University collection.

Induction Currents.—1. The galvanometer was connected with a coil of covered copper wire, No. 11 of the American wire gauge, about ten centimeters long and six in diameter, having a resistance of 0.323 ohm. A small bar magnet, 5 centimeters long and weighing six and a-half grams, gave, when introduced into the coil, a deflection of 40°. On withdrawing the magnet the needle moved 40° in the opposite direction.

2. A small coil, 20 centimeters long and 3.5 in diameter, made of No. 16 wire and having a resistance of 0.371 ohm, through which the current of a Grenet battery, exposing 4 square inches of zinc surface, was passing, was introduced into the centre of a large wire coil, whose resistance was 0.295 ohm, connected with the galvanometer. The deflection produced was 20°. The same deflection was observed on making and breaking contact with the battery, the smaller coil remaining within the larger.

3. A coil of No. 14 copper wire, sixty centimeters in diameter, and containing about 40 turns, the resistance of which was 0.85 ohm, was connected with the galvanometer, and placed on the floor. Raising the south side six inches, caused a deflection of 4°. Placing the coil with its plane vertical, a movement of two centimeters to the right or left, caused a deflection of 3°, and of twenty centimeters, of 10°. A rotation of 90° gave a deflection of 12° and one of 180°, of 24°. These deflections were of course due to currents generated by the earth's magnetism.

4. *Thermo-currents.*—Two pieces of No. 22 wire fifteen centimeters long, were taken, the one of copper, the other of iron wire, and united at one end by silver solder. On connecting the other ends to the galvanometer, the heat of the hand caused a deflection of the needle of 20°.

5. A thermo-pile of 25 pairs, each of bismuth and antimony, was connected to the instrument. The heat from the hand placed at five centimeters distance caused a deflection of 3°.

6. Two cubes of boiling water acted differentially on the pile. At the distance of five centimeters, the deflection was 20°; moving one to ten centimeters, the deflection was reduced to 5°.

7. *Voltaic current.*—A drop of water was placed on a zinc plate. While one of the connecting copper wires touched the zinc, the other was made to touch the water. The deflection was 16°.

The claim which is here made for the instrument however, is rather for the general principle of its construction, than for the advantages possessed by the individual galvanometer above described which was constructed at short notice, to meet an emergency. The comparatively small cost for which it may be fitted to the vertical lantern, the readiness with which it may be brought into use, the brilliantly illuminated circle of light which it gives upon the screen, with its graduated circle and needle, the great range of delicacy which may be given to the instrument by varying the coil and needles, so that all experimental requirements may be answered, and finally, the satisfactory character of its performance as a demonstration galvanometer, all combine to justify the record which is here made of it.

Philadelphia, April, 1875.